Project: CFS Stratosphere Improvement

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Progress Report Year 1

Results and Accomplishments:

1) Developing observational constraints for CFS model evaluation

We analyzed reanalysis data to determine characteristic features of the dynamical coupling between the extratropical circulation in the troposphere and stratosphere.
Downward wave coupling occurs when planetary waves reflected in the stratosphere impact the troposphere and is distinct from zonal-mean coupling which results from wave breaking and its impact on the zonal mean flow. Using cross-coherence correlation and wave geometry diagnostics we find that wave coupling in the southern hemisphere occurs from September to December in the presence of both a vertical reflecting surface in the stratosphere and a high-latitude meridional wave guide. In the northern hemisphere downward wave coupling is largest from December to March. The results highlight the distinction between wave reflection in general, which requires a vertical reflecting surface, and wave coupling between the stratosphere and troposphere, which requires both a reflecting surface and a meridional wave guide. The comparison between wave 1 and zonal mean processes illustrate that in the southern hemisphere, wave coupling is found to dominate downward coupling in spring (Fig. 1 left panel). In the northern hemisphere however wave coupling and zonal-mean coupling are found to be equally important during the active period from winter to early spring (Figure 1, right panel). The results suggest that an accurate representation of the seasonal cycle of the wave geometry is necessary for a proper representation of downward wave coupling The results are used to evaluate the troposphere-stratosphere coupling in the CFS.

2) Model evaluation and development:

Preamble: Until today (at the time of the progress report), we do not have available the new version of the CFS which is supposed to be the baseline model for model improvement and evaluations. Thus, our studies are based on other models (e.g., Canadian Middle Atmosphere model, CMAM), and interim versions of the CFS and its atmospheric circulation model GFS_{CFS}.

a) The impact of stratospheric model configuration on modeled planetary scale waves in northern hemisphere winter is examined using the CMAM Model. The CMAM configurations include a high-lid (0.001 hPa) and a low-lid (10 hPa) configuration, which were each run with and without conservation of parameterized gravity wave momentum. The planetary wave structure, vertical propagation and the basic state are found to be in good agreement with reanalysis data for the high-lid conservative configuration with the exception of the downward propagating wave one signal.

When the lid is lowered and momentum is conserved, the wave characteristics and basic state are not significantly altered, with the exception of the downward propagating wave one signal, which is damped by the act of conservation. However when momentum is not conserved the wave amplitude increases significantly near the lid, there is a large increase in both the upward and downward propagating wave one signals and a significant increase in the strength of the basic state. The impact of conserving parameterized gravity wave momentum flux is found to be much larger than that of the model lid height. It is shown that the changes to the planetary waves and basic state significantly impact the stratosphere-troposphere coupling in the different configurations.

b) At the moment, we are carrying out a AMIP style simulation with a recent version of the GFS in T126 resolution. So, far 13 years of the simulation are analyzed starting 1970. We compared this simulation with ERA40 Reanalysis (22 years, 1979-200O). The main results of this evaluation are as follows:

- The analysis of the climatology of zonal mean zonal wind:
    - During November to March, the polar vortex in the Northern Hemisphere lower stratosphere is too weak.
    - Variability in the Northern Hemisphere lower stratosphere is too weak during late winter/early spring (Feb, Mar).
    - The Southern Hemisphere Polar Vortex during austral winter is too strong above 10hPa and is shifted poleward relative to reanalysis.
    - In the Southern Hemisphere, the poleward movement of maximum variability from July to November is well represented. The variability during spring is larger in the model than in Reanalysis.
- The analysis of meridional heat flux at 100 hPa
    - Flux of wave activity into the stratosphere is smaller in the GFS than in reanalysis. This bias occurs mostly in Feb-Apr in the Northern Hemisphere, and Aug-Nov in the Southern Hemisphere.
- Analysis of variability of zonal mean wind at 10hPa, 60N.
    - The analysis illustrates that the GFS is capable of simulating weak winds and major stratospheric sudden warmings (SSW).
    - The model is not able to simulate a strong polar night jet.
    - Since there is a negative bias in the flux of wave activity reaching the stratosphere, the anomalously weak Northern Hemisphere polar vortex in the GFS does not result from this bias.
- Analysis of features of dynamic troposphere-stratosphere coupling (Figure 2)
    - Zonal mean downward coupling in the Northern Hemisphere is well represented in the GFS most likely due to the fact that the GFS simulates SSW.
    - In the GFS, there is no wave 1 downward coupling in the Northern Hemisphere most likely because there is no meridional wave guiding due to the fact that vortex in the lower stratosphere is too weak.
    - Vertical propagation of wave 1 into the stratosphere is reduced in the NH relative to reanalysis.

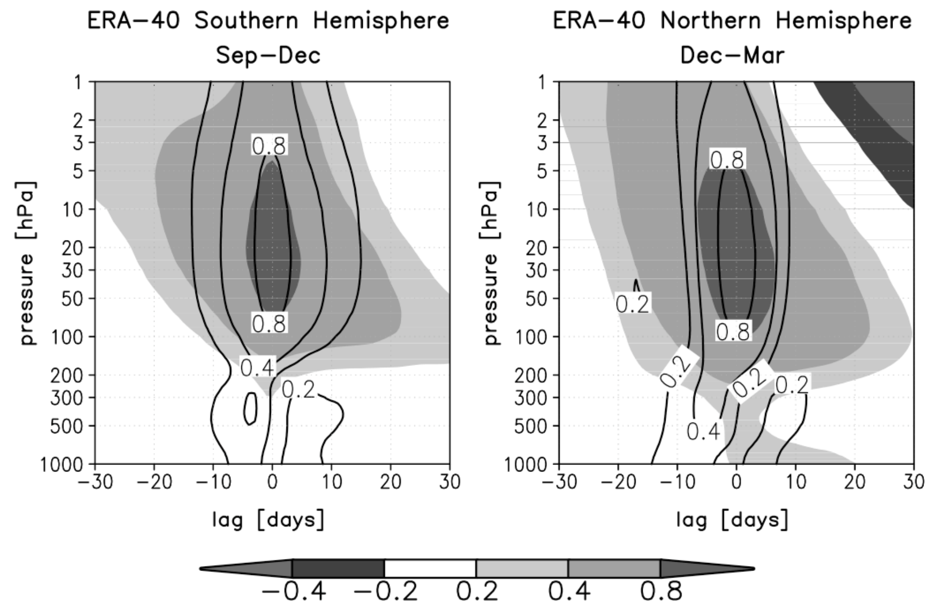

Figure 1: Lag-height sections of observed correlations between daily extratropical 20hPa height fields and height fields at pressure levels from 1000 to 1hPa. Shown are correlations of annular mode (zonal mean coupling, shaded), and wave 1 cross correlation (isolines) during active season of dynamical troposphere-stratosphere coupling, *left:* Southern Hemisphere (Sep-Dec), right*:* Northern Hemisphere (Dec-Mar)

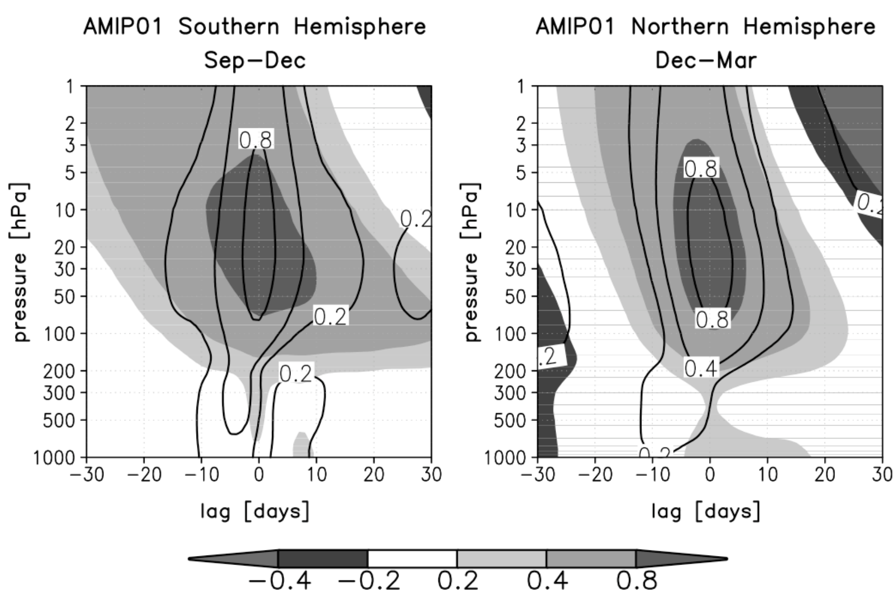

Figure 2: Same as Figure 1, but for the GFS-T126-AMIP01 simulation.

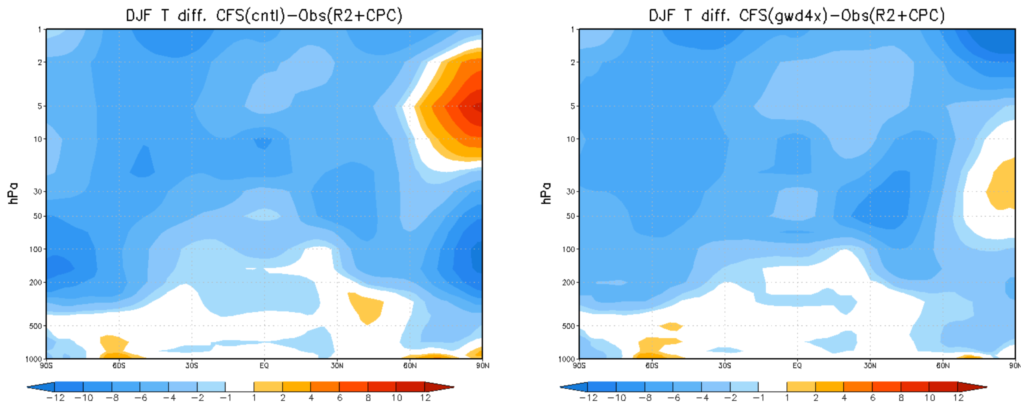

Figure 3: Zonal mean temperature bias in two simulations with a recent version of the CFS for the winter season 2009/2010. Left: baseline simulation, Right: GWDx4 experiment The simulations were compared with combined NCEP R2 reanalysis and stratospheric CPC analysis.

c) A main goal of this project is to tune the orographic gravity wave drag parameterization utilized in new CFS. This work is in progress. We are carrying out a 6 member ensembles of a seasonal prediction for 2009/2010 with a recent version of the CFS. In addition, we are carrying out an ensemble of simulations, in which the amplitude of the orographic gravity wave drag is modified. In Figure 3, the bias in zonal mean temperature for single simulations of the baseline and GWDx4 is shown. The results illustrate that the cold bias in the polar lower stratosphere is reduced in the experiment with the GWDx4 version. The analysis of the full ensemble is necessary to determine whether the results are robust. In addition, we carried out a series of five one-year integrations with the CFS to determine the impact of initial conditions on the bias. It is found that the biases are robust and do not depend on initial conditions.

Highlights of Accomplishments

- Main features of dynamical troposphere-stratosphere in the extra-tropics were determined. These results are the basis for the evaluation of troposphere-stratosphere coupling in the CFS.
- The impact of conserving parameterized gravity wave momentum flux is found to be much larger than that of the model lid height in low-lid models.
- An AMIP style simulation with a recent version of GFS (in T126 resolution) revealed relevant biases in the stratospheric basic state and dynamic troposphere-stratosphere coupling.
- First experiments in which the amplitude of the orographic gravity wave drag (GWD) was modified illustrate the sensitivity of the stratospheric basic state to the orographic GWD setting.

Publications from the Project:

Shaw, T. A. and J. Perlwitz, 2010: The impact of stratospheric model configuration on planetary scale waves in northern hemisphere winter, J. Climate in press.

Shaw, T. A., J. Perlwitz and N. Harnik, 2010: Downward wave coupling between the stratosphere and troposphere: the importance of meridional wave guiding and comparison with zonal-mean coupling, J. Climate, in preparation.

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